

Task Force on Planetary Defense

NEO Orbital Dynamics and Deflection

Briefing to NASA Advisory Council
5 August 2010

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1. What is an Impact?
2. What is a Keyhole?
3. What is a Deflection?
4. What will Trigger a Deflection Campaign?
5. What is a Deflection Campaign?
6. Primary Issues

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1. What is an Impact?

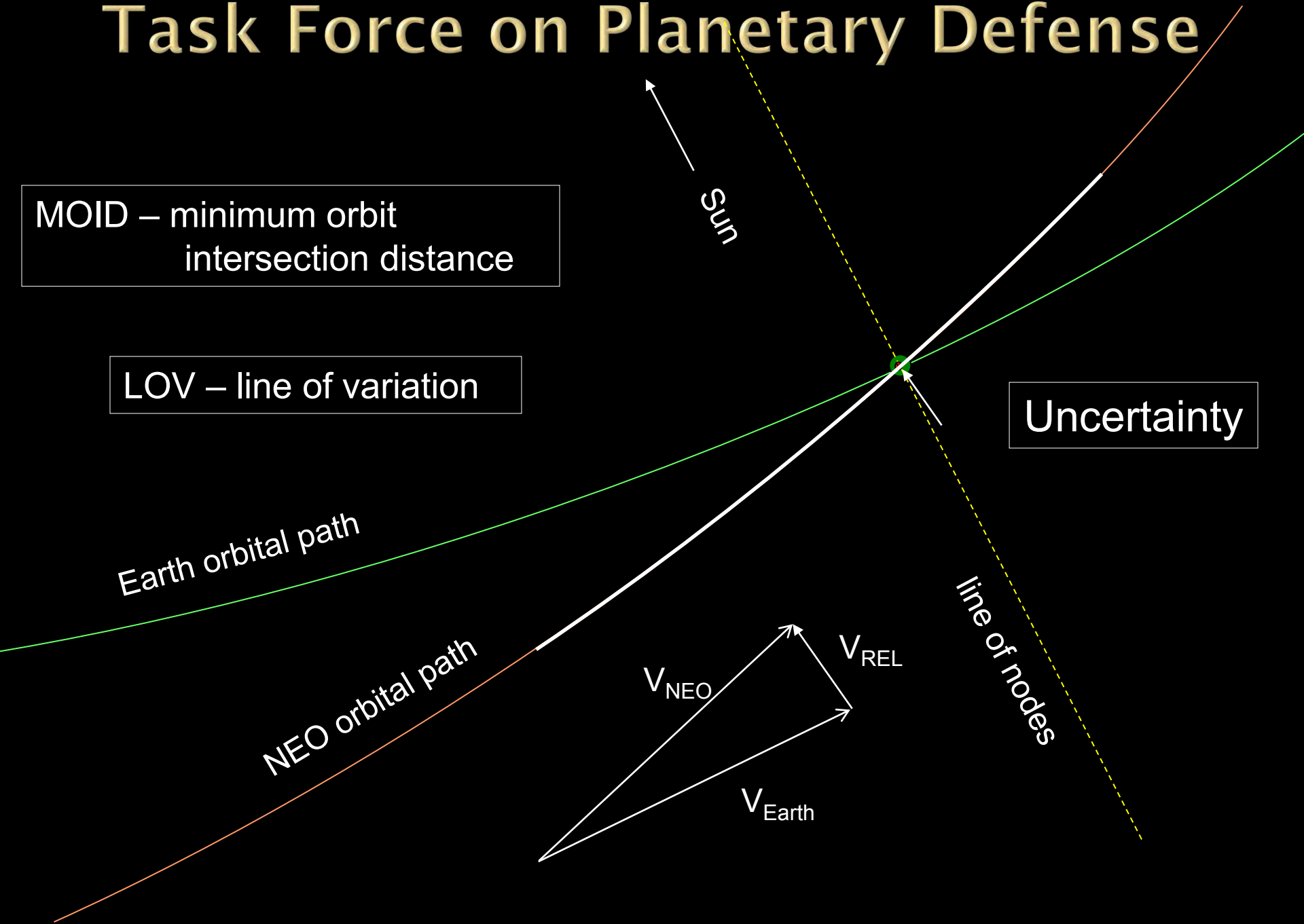
The coincident location of a NEO and the Earth (direct impact) or the NEO and a keyhole (keyhole impact) at the 3 dimensional intersection of the orbits of the Earth and the NEO

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MOID – minimum orbit
intersection distance

LOV – line of variation

Uncertainty



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Uncertainty

Apophis
Risk Corridor

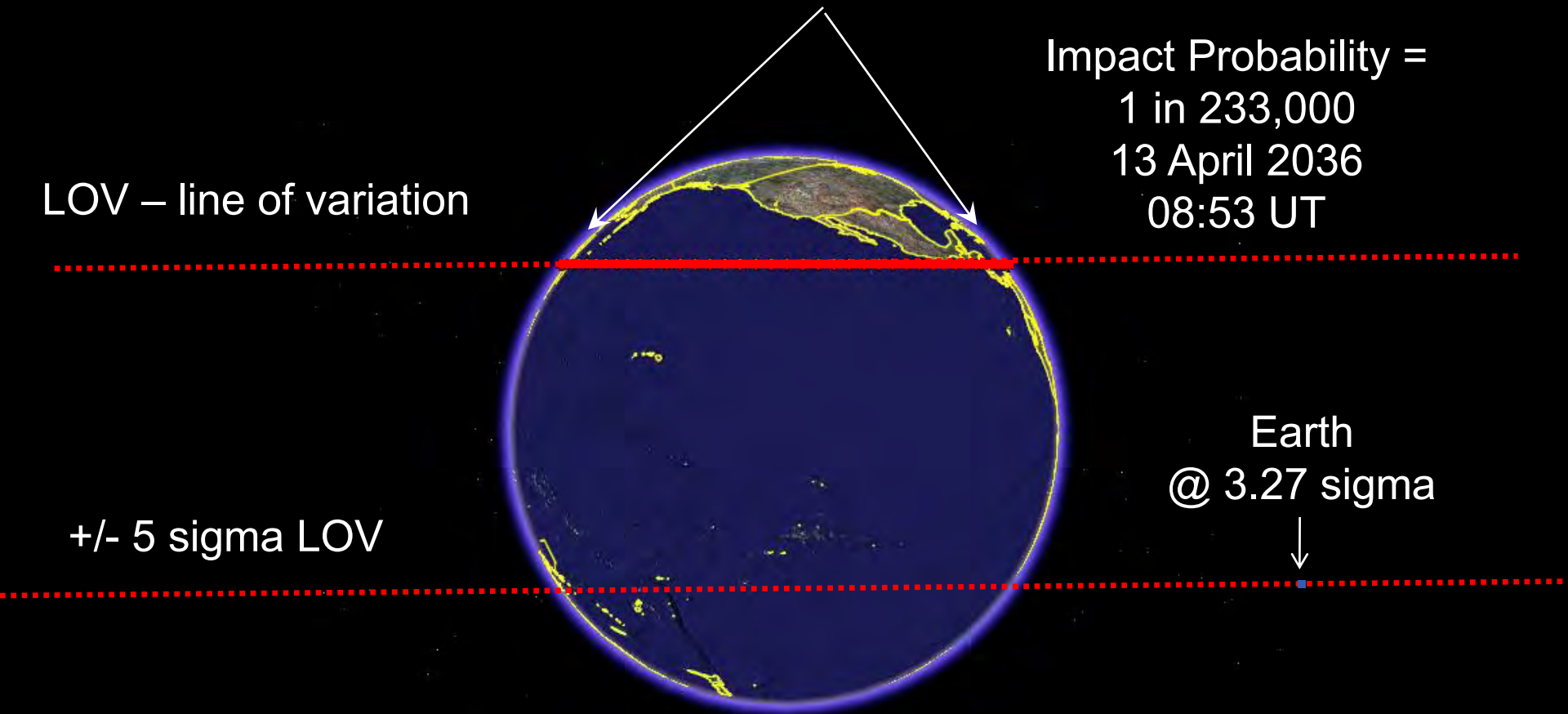
Impact Probability =
1 in 233,000
13 April 2036
08:53 UT

LOV – line of variation

+/- 5 sigma LOV

Earth
@ 3.27 sigma

12,840 kilometers



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2. What is a Keyhole?

One of a set of small regions along the LOV which, if a NEO passes through it, will cause the NEO to return “n” years later and impact Earth. (n = an integer)

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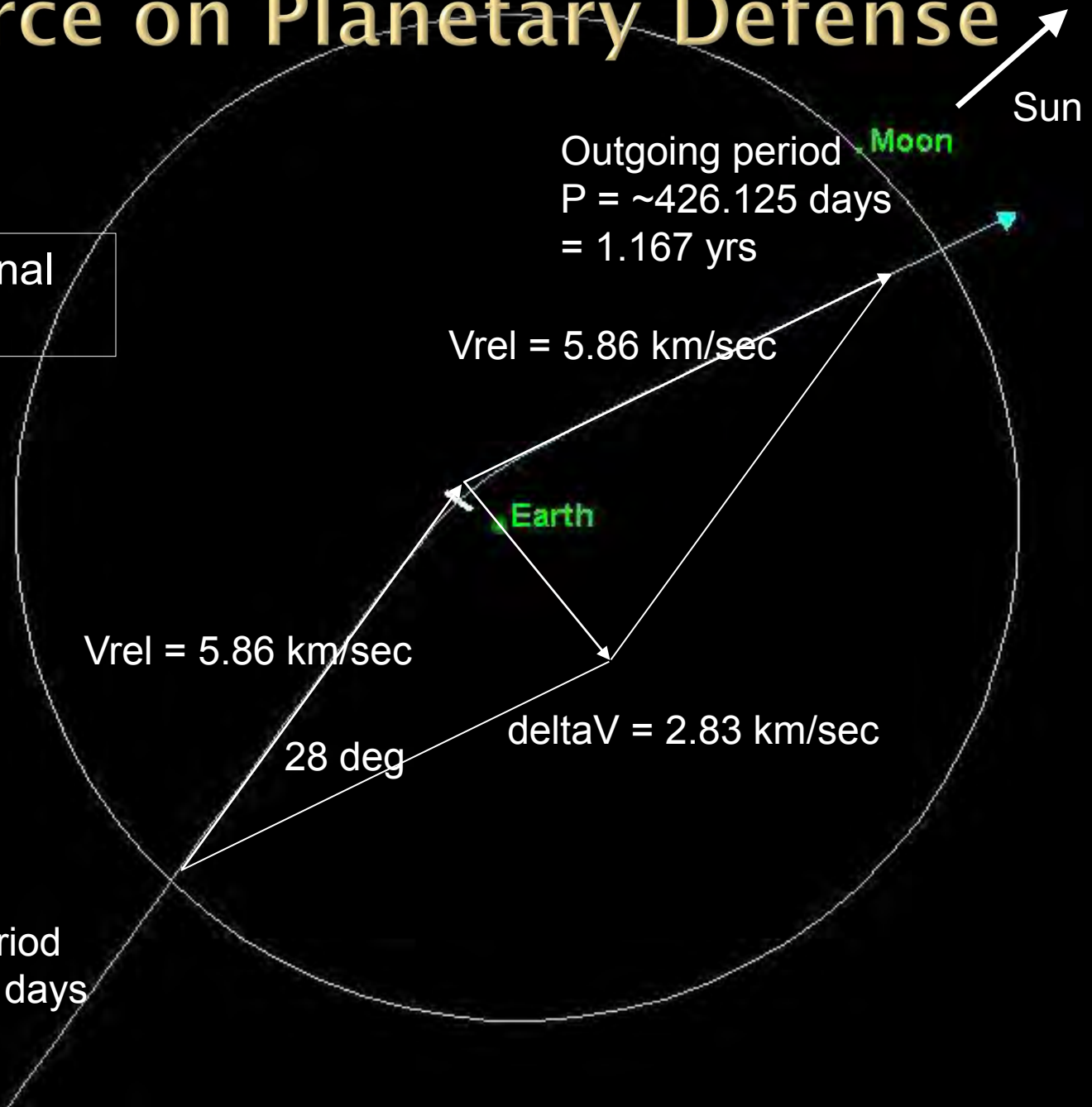
cge – close gravitational encounter

Apophis

close encounter
geometry

Friday, 13 April 2029
~21:00 UT

Incoming period
 $P = 323.588$ days
 $= 0.886$ yrs



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Total impulse required
 1.15×10^8 newton seconds
10,000+ kilometers



Primary Deflection =
Miss the Earth



Trim =
Guide between keyholes

7/6 Keyhole
Total impulse required
 1×10^4 newton seconds
0.6 kilometers



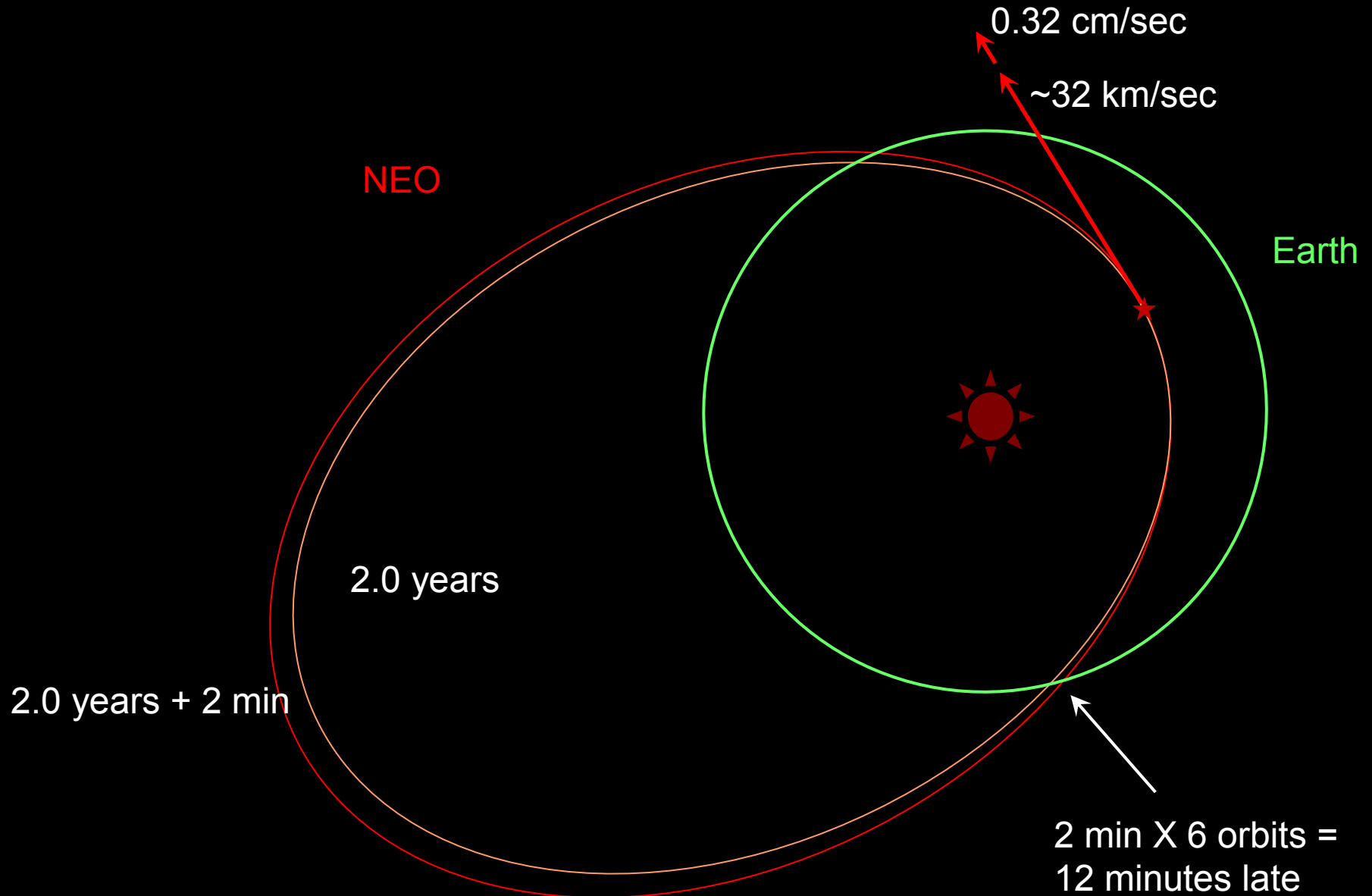
12,840 kilometers

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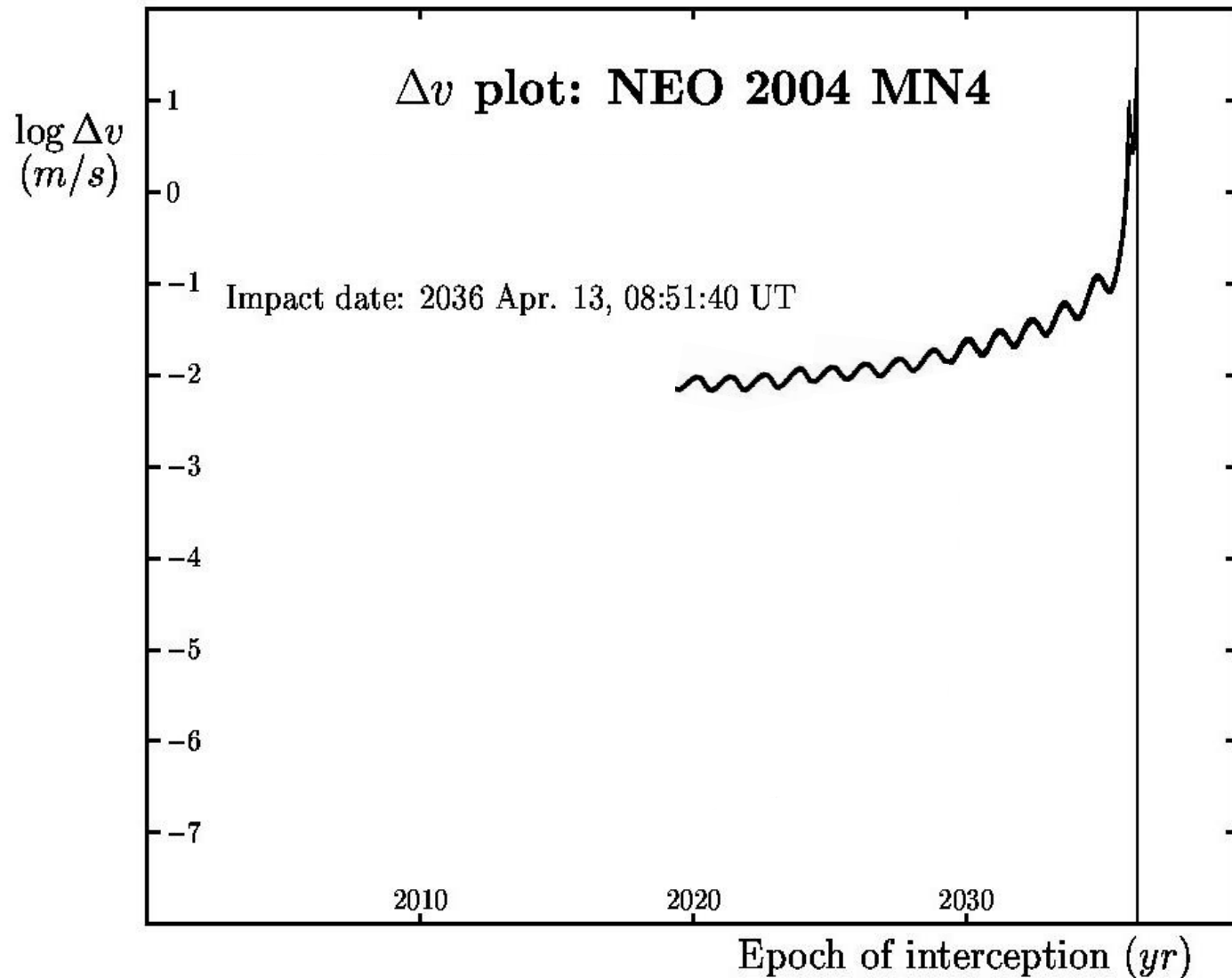
3. What is a Deflection?

A maneuver executed years prior to an impact which causes a small change in the velocity of a threatening NEO resulting in the NEO arriving either too early or too late to impact the Earth or a keyhole.

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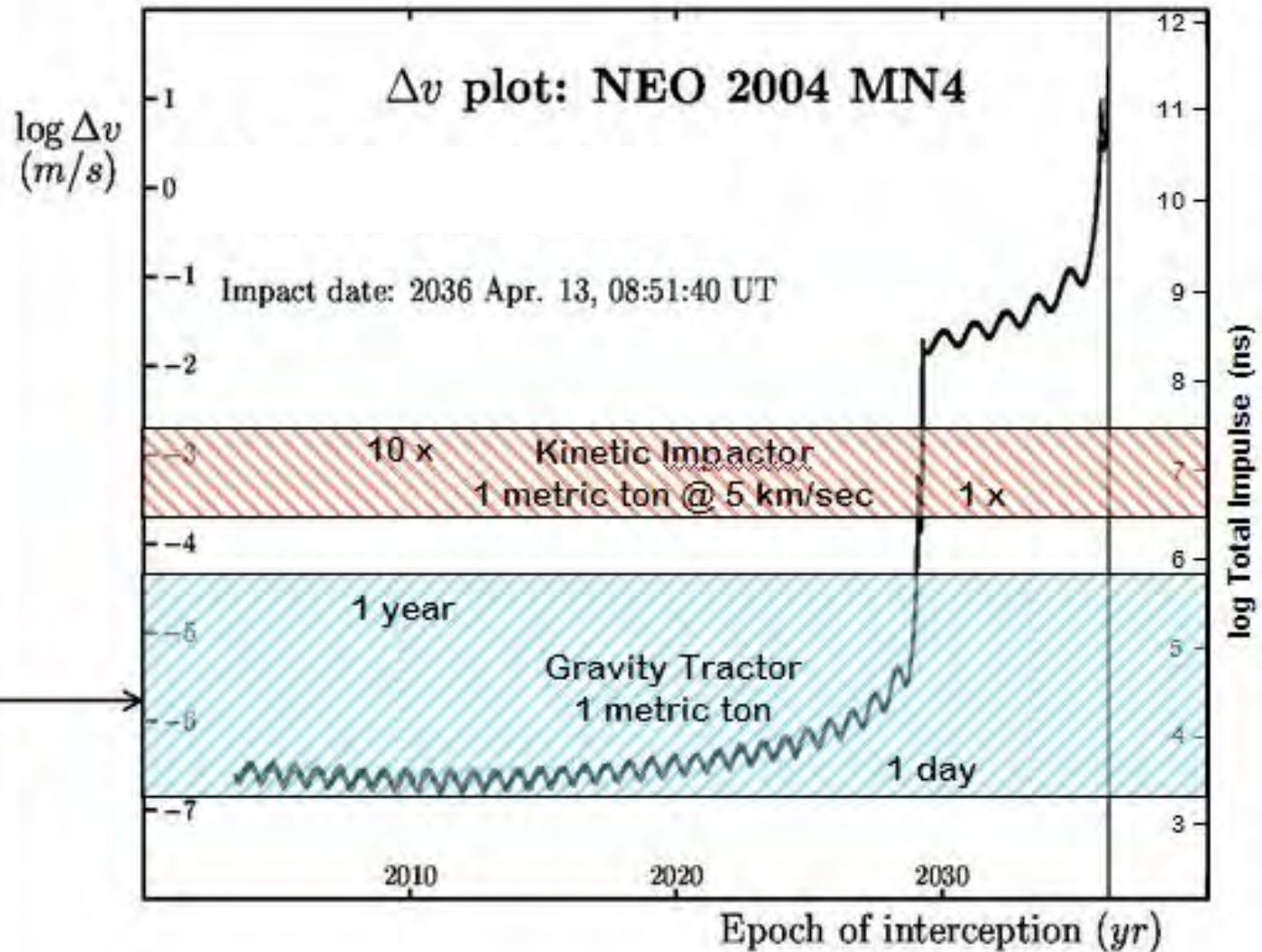


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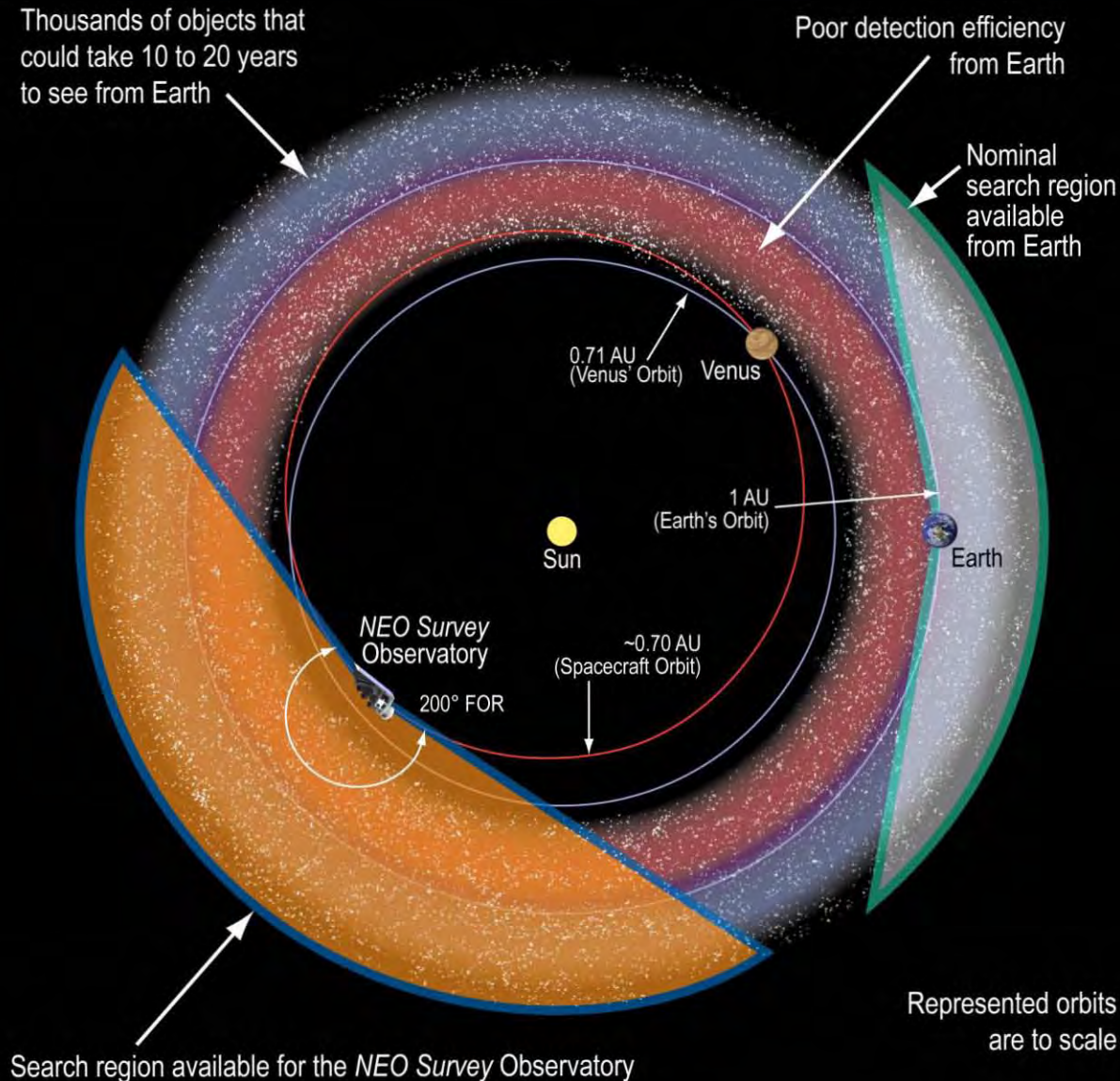


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Keyholes and ΔV requirement



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4. What Will Trigger a Deflection Campaign?

An unacceptably high probability of impact at or prior to the latest time that a deflection campaign can be initiated and be completed in time to prevent the impact.

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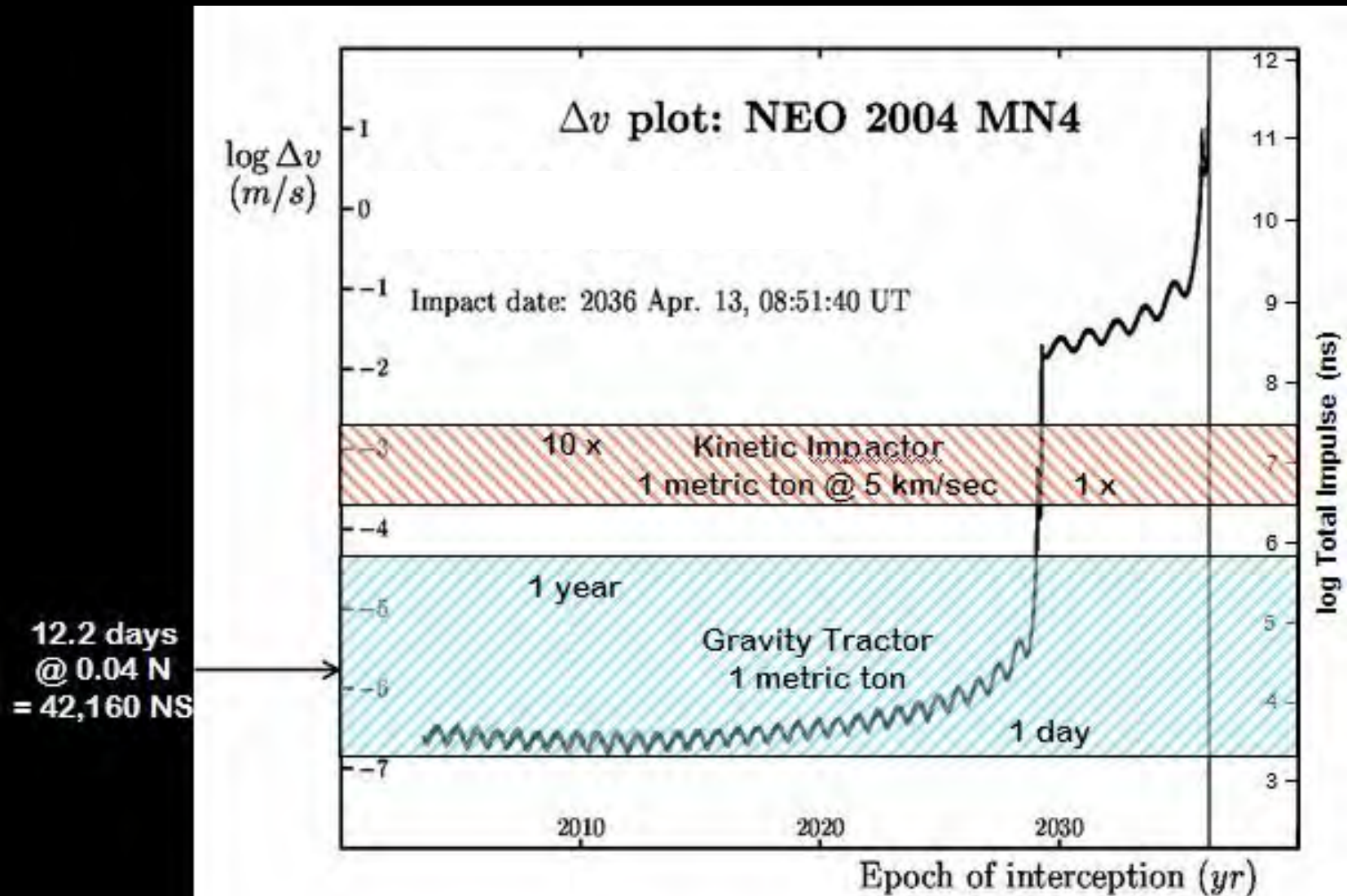
Time is Everything

The “Decision Time” (latest date a decision to deflect and still get the job done) must be backed up from the “impact epoch” by ~2–8 years for the deflection to have effect, ~1–3 years for rendezvous or encounter, and 5–7 years from decision to launch.

The decision challenge then is dominated by the probability of impact at this decision date, 8–18 years prior to the potential impact.

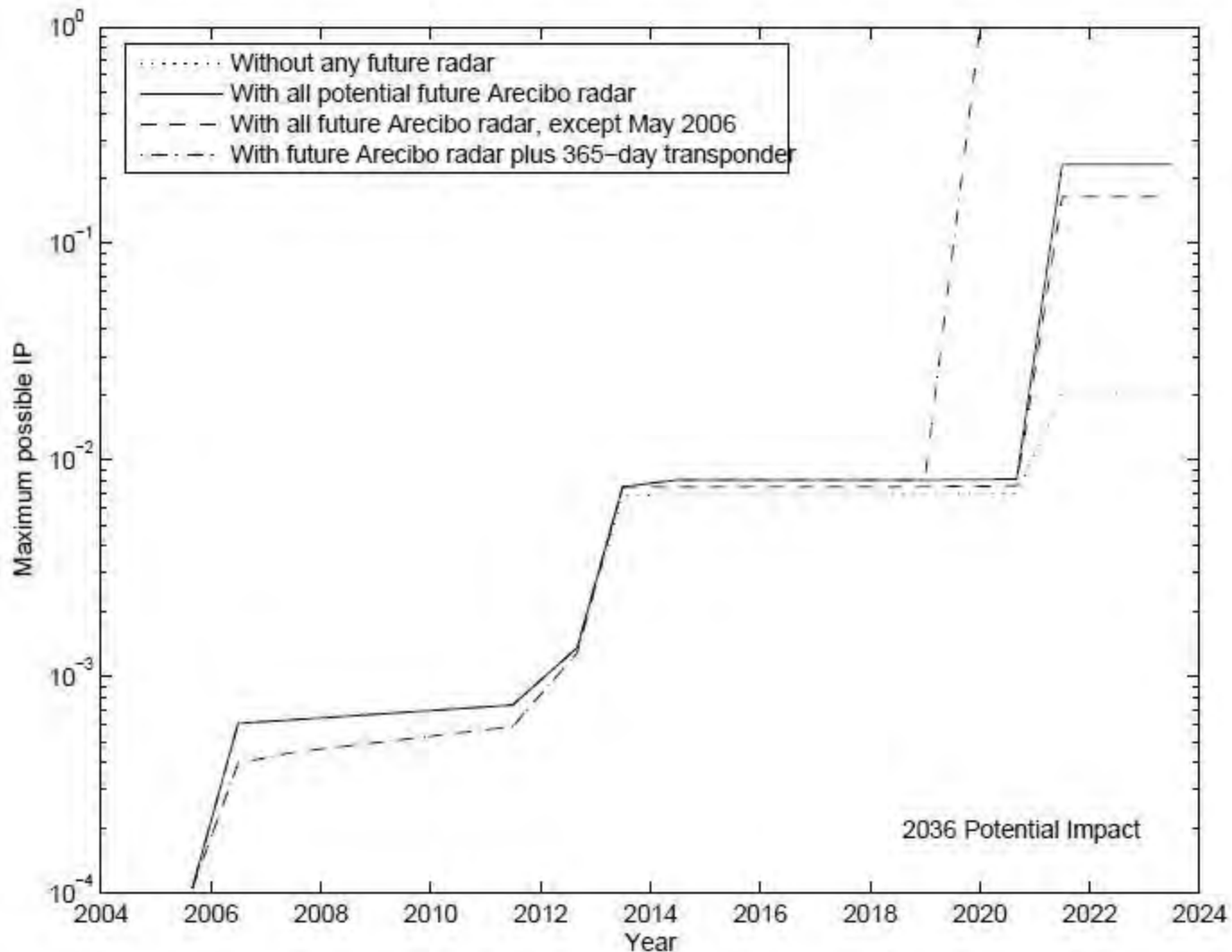
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Keyholes and ΔV requirement



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Maximum Impact Probability vs. Decision Time



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5. What is a Deflection Campaign?

For a direct impact; two (or more) coordinated missions to 1) precisely determine the NEO orbit, 2) execute the primary deflection (if required), 3) observe/confirm the primary deflection, 4) precisely determine the new NEO orbit, and 5) trim the new orbit to avoid a keyhole impact, if necessary.

For a keyhole impact; a single mission to 1) precisely determine the NEO orbit, and 2) adjust the NEO orbit to avoid a keyhole impact, if necessary.

[key: t/GT – xponder/Gravity Tractor; Kinetic Impactor]

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Current Deflection Capability

Kinetic Impact

Pushes the asteroid via
direct impact
(KI = robust but imprecise)



Gravity Tractor

Precisely determines NEO
orbit (via transponder)

Pulls the asteroid using
mutual gravity as a tow-rope
(GT = weak but precise)



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Standoff Nuclear Explosion

Explosively vaporizes
surface off NEO to create an
impulsive push
(robust but imprecise)



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6. Primary Issues

Uncertainty and variability in value of β
(momentum multiplier) for kinetic impacts

Uncertainty of fragmentation for both kinetic
impact and nuclear explosion

Validation of gravity tractor position control in
proximity to rotating NEO

**Need for full deflection campaign demonstration
for public and engineering confidence**